PATENT ABSTRACTS OF JAPAN

(11)Publication number : **08-068436**

(43)Date of publication of application : **12.03.1996**

(51)Int.Cl.
F16F 7/12
B60R 19/03
B60R 19/22
E01F 7/04

(21)Application number : **06-225739**

(22)Date of filing : **26.08.1994**

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(54) IMPACT ENERGY ABSORBING MEMBER MADE OF FOAM ALUMINIUM AND MANUFACTURE THEREOF

(57)Abstract:

PURPOSE: To increase energy absorbing quantity and reduce reaction at the time of impact by laminating plural foam aluminium material with the bulk specific gravity being within a specific range, and setting the deformation quantity, compressive stress, thickness, constants, and the like of the whole laminated body to the specific relation.

$$R_p = \sum_{i=1}^{n} R_i = \frac{b_p W_p}{100} \times a_p \frac{\sigma_p}{G_p} = \sum_{i=1}^{n} \frac{b_i W_i}{100} \times a_i \frac{\sigma_i}{G_i}$$

CONSTITUTION: Foam aluminium material with the bulk specific gravity being within a range of 0.05-0.6g/cc is laminated in plural layers. The relation expressed by a separately stated equation as an approximate expression is materialized among constants ai, bi and thickness Wi univocally determined according to the deformation quantity Ri compressive stress σp, thickness Wp and respective constants ap, bp of the whole laminated body and the deformation quantity Ri, compressive stress σi and bulk specific gravity Gi of single foam aluminium material. An impact energy absorbing member made of this foam aluminium is applied to an automobile bumper, an impact absorbing pad, a road side fence, or the like. The impact energy absorbing member large in energy absorbing quantity and small in reaction at the time of impact is

thereby obtained.

LEGAL STATUS

[Date of request for examination]

[Date of sending the examiner's decision of rejection]

[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's decision of rejection]

[Date of requesting appeal against examiner's decision of rejection]

[Date of extinction of right]

DERWENT-ACC-NO: 1996-197215

DERWENT-WEEK: 199620

TITLE: Aluminium foam impact absorption member for e.g. motor vehicle bumper - uses specific gravities ranging from 0.05 to 0.6 gram per cubic centimetre

PATENT-ASSIGNEE: NIPPON LIGHT METAL CO[NIMI]

PRIORITY-DATA: 1994JP-0225739 (August 26, 1994)

PATENT-FAMILY:

PUB-NO	PUB-DATE	LANGUAGE	PAGES	MAIN-IPC
JP 08068436 A	March 12, 1996	N/A	009	F16F 007/12

APPLICATION-DATA:

PUB-NO	APPL-DESCRIPTOR	APPL-NO	APPL-DATE
JP 08068436A	N/A	1994JP-0225739	August 26, 1994

INT-CL (IPC): B60R019/03, B60R019/22 , E01F007/04 , F16F007/12

ABSTRACTED-PUB-NO: JP 08068436A

BASIC-ABSTRACT:

The appts. has first aluminum foam attached to the second aluminum foam in a board. The **aluminum foam is supported by a reinforcing part and adhesive** layer. An impulsive force f gives the pressure impact absorption to the aluminum foam. The aluminum foams have different bulkiness specific gravities ranging from 0.05 to 0.6 gram per cubic centimetre.

Compressive strength of the overlapped aluminum foam increased due to the combined materials. The layered structure constitute different bulkiness specific gravities shown in the transformation rate-compressive stress curve.

USE/ADVANTAGE - Used for e.g. impact absorption pad, side fence, protection container and as an interior material. Reliably adjusts impact absorptivity according to usage. Lowers yield strength and increases compressive stress integration value. Collision damage-power is suppressed.

CHOSEN-DRAWING: Dwg.1/12

TITLE-TERMS: ALUMINIUM FOAM IMPACT ABSORB MEMBER MOTOR VEHICLE BUMPER SPECIFIC

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CLAIMS

[Claim(s)]
[Claim 1] Relative bulk density Gi It has the structure which carried out two or more laminatings of the foaming aluminum material in the range which is 0.05-0.6g/cc, and they are the deformation Rp of the whole layered product, compressive-stress sigmap, thickness Wp, a constant ap, and bp. The deformation Ri of single foaming aluminum material, compressive-stress sigmai, and relative bulk density Gi The constant ai which responds and becomes settled uniquely, and bi And thickness Wi In between, it is [Equation 1] as an approximate expression.

$$R_p = \sum_{i=1}^{n} R_i = \frac{b_p W_p}{100} \times \ell n \frac{\sigma_p}{a_p} = \sum_{i=1}^{n} \frac{b_i \cdot W_i}{100} \times \ell n \frac{\sigma_i}{a_i}$$

The striking-energy absorption member made from foaming aluminum in which ****** is materialized.
[Claim 2] The bumper for automobiles which used the striking-energy absorption member made from foaming aluminum according to claim 1.
[Claim 3] The impact-absorbing pad which used the striking-energy absorption member made from foaming aluminum according to claim 1.
[Claim 4] The road-side fence which used the striking-energy absorption member made from foaming aluminum according to claim 1.
[Claim 5] Interior material which used the striking-energy absorption member made from foaming aluminum according to claim 1.
[Claim 6] The guard vessel made in the striking-energy absorption member made from foaming aluminum according to claim 1.
[Claim 7] The manufacture approach of the striking-energy absorption member made from foaming aluminum which sticks with adhesives two or more foaming aluminum material from which requirements according to claim 1 are satisfied, and relative bulk density differs mutually.

[Translation done.]

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the impact-absorbing member used as interior material of an impact-absorbing pad, a guard vessel, a road fence, the bumper for automobiles, and various means of transportation etc.
[0002]
[Description of the Prior Art] It considers as the impact-absorbing member which absorbs the striking energy added from the outside as plastic deformation, and metal foam is used. Unlike rubber, a spring, etc. using elastic deformation, metal foam absorbs striking energy by plastic deformation without stability, i.e., the process in which foam itself is destroyed. Since the energy once absorbed by elastic stability etc. is not given to partner material when using plastic deformation, big impact absorbing power is presented. As this kind of metal foam, initial impact absorbing power is raised by carrying out plastic deformation beforehand by JP,47-8053,A. Moreover, in JP,49-40214,A, the impact absorber to which compressive strength was reduced is introduced by punching a right angle to the direction where the force is added, and adjusting voidage in 5 - 60% of range.
[0003]
[Problem(s) to be Solved by the Invention] Although metal foam presents big impact absorbing power, its reaction force at the time of a collision is still large. The reaction force at the time of a collision can be reduced by punching metal foam like a JP,49-40214,A publication. However, to an impact parallel to the punching direction, the effectiveness by punching is small and an anisotropy is in energy-absorbing ability. Moreover, although initial deformation resistance becomes small, as for the metal foam which carried out plastic deformation beforehand, the amount of energy-absorbing as the whole decreases. The amount of energy-absorbing of this invention is large by being thought out that such a problem should be solved and carrying out the laminating of the metal foam from which a property differs, and the reaction force at the time of a collision aims at offering a small striking-energy absorption member.
[0004]
[Means for Solving the Problem] The striking-energy absorption member of this invention is relative bulk density Gi, in order to attain the purpose. It has the structure which carried out two or more laminatings of the foaming aluminum material in the range which is 0.05-0.6g/cc. The deformation Rp of the whole layered product, compressive-stress sigmap, thickness Wp, a constant ap, and bp The deformation Ri of single foaming aluminum material, compressive-stress sigmai, and relative bulk density Gi The constant ai which responds and becomes settled uniquely, and bi And thickness Wi In between It is characterized by having materialized the relation of a degree type.
[0005]
[Equation 2]

$$R_p = \sum_{i=1}^{n} R_i = \frac{b_p W_p}{100} \times \ell n \frac{\sigma_p}{a_p} = \sum_{i=1}^{n} \frac{b_i \cdot W_i}{100} \times \ell n \frac{\sigma_i}{a_i}$$

[0006] This striking-energy absorption member is used as interior material of an impact-absorbing pad, a guard vessel, a road fence, the bumper for automobiles, and various means of transportation etc. The 1st foaming aluminum material and the 2nd foaming aluminum material are stuck in one by soldering or adhesives. At this time, it is desirable to pile up through the aluminum plate or foil of a solid so that the opening section of each foam may be filled up neither with wax material nor adhesives. When carrying out the compression set of the various ingredients, as shown in drawing 1 , according to the description of an ingredient, the relation between the reduction of area and compressive stress differs. In addition, the reduction of area in drawing 1 is expressed with [(thickness before compression) -(thickness after compression)]/(thickness before compression) x100(%). In the polyurethane foam currently used widely as a charge of an impact absorber, the field which carries out elastic deformation according to the applied compressive force is very small, and reaches yield strength A according to slight compressive force. then, it becomes the plateau region AB where the reduction of area rises under the compressive stress carried out about 1 law. If the reduction of area exceeds a B point, compressive stress will start rapidly and will reach C point. The absorbed amount of striking energy is proportional to the integral value of the compressive stress shown by drawing 1 .
[0007] Since there is little elastic deformation of O-A, polyurethane foam has an advantage with small impact reaction force. However, there are few integral values of compressive stress, i.e., the absorbed amount of striking energy, and it cannot say it as the outstanding striking-energy absorber. Since yield strength is high as compared with polyurethane foam, the elastic deformation of foaming aluminum of O-A has increased. If an elastic-deformation field is crossed, it will become plateau region A-B to which deformation advances under the fixed compressive stress. In plateau region A-B, crushing of the cell wall of foaming aluminum is carried out serially, and plastic deformation advances. If crushing of most cell walls is carried out, compressive stress will start rapidly and will reach C point.
[0008] The compressive stress of plateau region A-B is in high level as compared with polyurethane foam. Therefore, as compared with polyurethane foam, the integral value of compressive stress, i.e., the absorbed amount of striking energy, is very large, and it turns out that foaming aluminum is suitable as a striking-energy absorber. When the compressive force which intersects perpendicularly with the field of an aluminum sheet is applied, the aluminum honeycomb which sandwiched the honeycomb between the aluminum sheets of two sheets takes the reduction-of-area-compressive-stress curve shown in drawing 1 as an ingredient 3, so that the front face of an aluminum sheet and the hexagonal prism-like space of a honeycomb may cross at right angles. The yield strength A at this time is still higher than foaming aluminum, when yield strength A is exceeded, compressive stress once falls, and it results in plateau region A-B in which a honeycomb decays successively.
[0009] Since elastic-deformation region O-A is large, such an aluminum honeycomb serves as an impact-absorbing member which reaction force is large and is inferior in an initial impact absorption. Moreover, when compressive stress joins the field of an aluminum sheet, and parallel, a completely different reduction-of-area-compressive-stress curve is shown. That is, the impact-absorbing member created by the aluminum honeycomb has the large anisotropy of impact absorbing power, and in order to acquire expected impact absorbing power, constraint is received in the anchoring posture over partner material. If the aluminum cylinder which attached two or more breaks about a hoop direction and shaft orientations, respectively is used as an impact-absorbing member, the reduction-of-area-compressive-stress curve shown in drawing 1 as an ingredient 4 will be obtained. At this time, the compressive stress to apply was made in agreement with cylindrical shaft orientations. Two or more waves seen to the field beyond yield strength A show the condition attached to the cylinder that crushing of the aluminum material is carried out for every break. Also in this case, yield strength A is high and a problem is in an early impact absorption. Moreover, in radial [cylindrical shaft orientations and radial / cylindrical], reduction-of-area-compressive-stress curves differ greatly and serve as an impact-absorbing member with the problem which originates in the anisotropy of impact absorbing power like an aluminum honeycomb.
[0010] When contrasting various ingredients as mentioned above, yield strength is small, the foaming

aluminum with the integral value of compressive stress large moreover has the small reaction force at the time of a collision, it excels in an initial impact absorption, and it is suitable that the absorbed amount of striking energy is large as an impact-absorbing member demanded. This invention is developed that the advantage of the foaming aluminum which presents the property which was excellent as an impact-absorbing member should be utilized further. Generally the foaming aluminum made with the same ingredient differs in yield strength according to voidage. So, in the impact-absorbing member which piled up the foaming aluminum from which voidage differs, if compressive force is added, crushing will be carried out to order from what has small yield strength. Therefore, the repulsive force at the time of a collision is small, and the outstanding initial impact absorbing power presents. And since the place where yield strength depends on big foaming aluminum is large, as for the compressive stress in Prato region A-B, the integral value of compressive stress, as a result the absorbed amount of striking energy also become large as a result.
[0011] The laminating of the foaming aluminum from which voidage differs is carried out by proper number of sheets if needed. It is practical to pile up various foaming aluminum for relative bulk density as a standard of voidage on the occasion of a laminating. Namely, relative bulk density Gi When carrying out two or more laminatings of the foaming aluminum material in the range which is 0.05-0.6g/cc, The deformation Rp of the whole layered product, compressive-stress sigmap, thickness Wp, a constant ap, and bp The deformation Ri of single foaming aluminum material, compressive-stress sigmai, and relative bulk density Gi The constant ai which responds and becomes settled uniquely, and bi And thickness Wi In between The physical properties of each foaming aluminum material are chosen so that the relation of a degree type may be materialized.
[0012]
[Equation 3]

$$R_p = \sum_{i=1}^{n} R_i = \frac{b_p W_p}{100} \times \ell n \frac{\sigma_p}{a_p} = \sum_{i=1}^{n} \frac{b_i \cdot W_i}{100} \times \ell n \frac{\sigma_i}{a_i}$$

The relative bulk density of foaming aluminum is adjusted by the class of foaming agent added to an aluminum molten metal, particle size, an addition, foaming conditions, the cooling conditions of a molten metal, etc. SiC, aluminum 2O3, MgO, C, etc. are used for a foaming agent. As aluminum by which foaming processing is carried out, although the quality of the material is not restrained specially, all aluminum ingredients, such as an aluminum-Si system, an aluminum-Cu system, an aluminum-Mg system, an aluminum-Mn system, and a pure aluminum system, are used.
[0013]
[Function] when compressive force is applied to the impact-absorbing member which carried out the laminating of the foaming aluminum from which relative bulk density differs, relative bulk density is small first -- if it puts in another way, the 1st foaming aluminum with low yield strength will start plastic deformation. the start point of plastic deformation -- the fall of yield strength -- responding -- **** of a collision -- it can be set as an early phase. Thereby, reaction force at the time of a collision is made small, and striking energy can be absorbed as plastic deformation from an early phase. In the phase which follows, the big 2nd foaming aluminum of yield strength deforms plastically. Therefore, plateau region A-B shown in drawing 1 is set to level with high compressive stress, and the integral value of compressive stress, i.e., the absorbed amount of striking energy, becomes large.
[0014] this time -- the relative bulk density of the 1st foaming aluminum -- and by choosing suitably under the conditions which showed above combination with the relative bulk density of the 2nd foaming aluminum, the reaction force at the time of a collision is fully lowered, and a energy-absorbing member with a striking-energy absorbed amount big moreover is obtained. Moreover, it also becomes possible to give the property according to the purpose of use by changing the laminating number of sheets of the foaming aluminum from which relative bulk density differs mutually. The striking-energy absorption member which presents the outstanding property is obtained by measuring beforehand the compressive-

stress-reduction-of-area curve shown in drawing 1 about each foaming aluminum, and choosing the 1st foaming aluminum 1 and the 2nd foaming aluminum with the voidage corresponding to desired value from the above thing.
[0015]
[Example]
Example 1 : (decision of a reduction-of-area-compressive-stress curve)
About a foaming aluminum ingredient with the various relative bulk density Gn (g/cc), it is the reduction of area En. When asked for the relation between (%) and compressive-stress sigman (N/mm2) by experiment, it turned out that there is relation shown in drawing 2 . For example, relative bulk density had the reduction-of-area-compressive-stress curve shown as G0.05 in drawing 2 with the foaming aluminum ingredient which is 0.05g/cc. This reduction-of-area-compressive-stress curve considers that it is shown by the formula (1), and is a constant an. And bn It computes by substituting for a degree type (1) the numeric value of the graph obtained in the experiment about the foaming aluminum ingredient with each relative bulk density. A calculation result is shown in Table 1.
[0016]
[Equation 4]

$$\left.\begin{aligned} G_{0.05} &: \ell n(\sigma_{0.05}) = \ell n(a_{0.05}) + b_{0.05} \times E_{0.05} \\ G_{0.1} &: \ell n(\sigma_{0.1}) = \ell n(a_{0.1}) + b_{0.1} \times E_{0.1} \\ G_{n} &: \ell n(\sigma_{n}) = \ell n(a_{n}) + b_{n} \times E_{n} \end{aligned}\right\} \cdots\cdots (1)$$

[0017] When designing the combination of various foaming aluminum material, a concrete dimension is defined from the target amount of absorbed energies. Then, the relation between compressive stress and deformation is needed. Reduction of area En (%) and deformation Rn The relation with (mm) is Wn about the thickness of a foaming aluminum ingredient. It is expressed with a degree type (2) when (mm).
En =Rn/Wn x100 .... (2)
On a design, it is deformation Rp concretely. Since it is required, it is compressive-stress sigmap. Deformation Rp It is each relative bulk density Gn so that it may illustrate to drawing 3 , in order to find relation. Corresponding sigman Rn The graph of relation is needed. A degree type (3) is obtained from a formula (1) and a formula (2). Namely, deformation Rn corresponding to compressive-stress sigman Thickness Wn Relation is called for as a formula (3).
[0018]
[Equation 5]

$$\begin{aligned} \ell n(\sigma_{n}) &= \ell n(a_{n}) + b_{n} \times E_{n} \\ &= \ell n(a_{n}) + b_{n} \times \frac{R_{n}}{W_{n}} \times 100 \quad \cdots\cdots (3) \end{aligned}$$

[0019] Here, it is an. And bn Each relative bulk density Gn It corresponds and asks with the empirical formula. Therefore, Wn sigman-Rn corresponding to it if it sets to arbitration A curve can draw from count of a formula (3) (drawing 4). Moreover, the whole thickness Wp It is determined on the service condition on a design. Therefore, specified thickness Wp It is Wn so that it may become smallness. It is decided that it will be arbitration and a respectively independent reduction-of-area-compressive-stress curve is drawn (drawing 4). drawing 4 -- setting -- Wp = -- time he wants relation Wp =(Gp) W100 (G100) of deformation-compressive stress at 100mm -- sigman it is -- Rn =sigmaRi at the time Target line Wp it rides -- as -- Wi Several are selected. Specifically, it is drawing 4 sigma1 at R> 4. It solves and is R3 =R1+R2. Two, W25 and W75, are chosen so that it may become. Namely, Wp It turns out that what is necessary is just to pile up two, W25 and W75, although obtained. If this is said by the general formula, Wi (Gi) will be chosen so that it may become a degree type (4).

[0020]
[Equation 6]

$$R_p = \sum_{i=1}^{n} R_i \qquad \cdots\cdots (4)$$

[0021] And it is sigma1 and sigma2 for finding the combination of the curve which satisfies this relation... sigman It calculates in a try and an error and is Rn =sigmaRi. A curve which becomes is chosen. this invention person etc. is the value Rp which is in target within the limits from much experiments according to a formula (4). It checked being obtained. A formula (5) and a formula (4) to desired value Rp changed from the formula (3) The formula (6) to express is called for. A formula (6) is an approximation-general formula called for as a result of this invention.
[0022]
[Equation 7]

$$R_n = \ell n \left(\frac{\sigma_n}{a_n} \right) \times \frac{W_n}{100} \times b_n \qquad \cdots\cdots (5)$$

$$R_p = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \left[\ell n \left(\frac{\sigma_i}{a_i} \right) \times \frac{W_i}{100} \times b_i \right] \cdots\cdots (6)$$

[0023] The constant ai in a formula (6) and (an) bi (bn) were calculated as follows from experimental data in connection with relative bulk density Gi (Gn) by substituting the actual measurement of drawing 2 of a formula (1).
[0024]
[Table 1]
表1：定数a_n及びb_nと嵩比重G_nとの関係

嵩比重G_n	定　数	
g／cc	a_n	b_n
0.10	0.11	3.2
0.15	0.63	1.35
0.25	1.42	1.35
0.30	1.49	1.93
0.54	5.23	2.65

[0025] The data of Table 1, and the relation of a formula (3) to Gn It is thickness Wn when it is 0.1. If it decides, it is compressive-stress sigman. And deformation Rn A graph is Wn freely. It turns out that it is made to change and a large number can be drawn. Relative bulk density Gn Value Rp approximated to desired value by selecting and compounding a predetermined graph out of the graph changed variously It can obtain. concrete -- curve Wp of desired value Thickness Wp 100mm in the total thickness of a design value etc. -- setting -- subsequently -- Gi The corresponding constant ai and bi using it -- thickness Wn the formula (3) changed by 100mm or less -- every -- Gi It receives, and it graph-izes and many curves of drawing 4 about a single member are drawn. At this time, it is a certain constant sigman. The combination of Curve Wn (Gn) is chosen so that the curve of a single member may surely come to left-hand side rather than a target curve about a value. Thereby, it is desired value Rp =R1+R2+... +Rn =sigmaRi Curve Wi is partly chosen so that it may be materialized. At this time, it is the total thickness

Wp. In the range restrained, it is thickness Wn. Relative bulk density Gn The curved combination which it has exists innumerably. Then, in consideration of the ease on manufacture, near and combination choose and lay the easiest thing on top of desired value most. Thereby, they are superposition and the predetermined desired value Wp about the thing which is relative bulk density and from which thickness differed and it differed. The product which it has is obtained.
[0026] Example 2 : (investigation of the property which piled up the foaming aluminum from which voidage differs)
In order to raise the viscosity of a molten metal for aluminium alloy AC4C which made 15 % of the weight of SiC particles with a mean particle diameter of 10 micrometers contain and to promote a foaming reaction, it dissolved at 740 degrees C. The air injection shaft was inserted in the obtained aluminum molten metal, the compressed air was blown into the molten metal, rotating an air injection shaft at the molten metal temperature of 700-650 degrees C, and the foaming layer was formed. After carrying out continuation coagulation of this foaming layer on a belt-like rotation cooling object, it cut and foaming aluminum with width of face of 600mm, a die length [of 2000mm], and a thickness of 100-200mm was manufactured. At this time, the relative bulk density of foaming aluminum was adjusted to the range of 0.05-0.55g/cc by changing the blowing-in flow rate of the compressed air, the rotational speed of an air injection shaft, etc.
[0027] Foaming aluminum of 0.05g/cc of relative bulk density was started on the one-side 80mm cube, impulse force was applied, and the relation of reduction-of-area-compressive stress was investigated. As drawing 5 R> 5 which shows results of an investigation saw, it was the same reduction-of-area-compressive-stress curve substantially also about any of the direction of L, the direction of LT, and the direction of ST. This shows that foaming aluminum does not have an anisotropy about the absorbing power of striking energy. Next, the obtained foaming aluminum was piled up as shown in drawing 6 . That is, sizing of each foaming aluminum was carried out to 100mmx100mm magnitude, and the thickness of each foam 1 and 2 was adjusted so that the sum total thickness of the 1st foaming aluminum 1 and the 2nd foaming aluminum 2 might be set to 100mm. Moreover, the layered product which stuck the 1st foaming aluminum 1 and the 2nd foaming aluminum 2 was obtained in the adhesives layer 3 which used urethane foam (test numbers 1 and 2 of Table 2).
[0028] The impulse force F which goes to an adhesion side direct was applied to the layered product, and the amount of energy-absorbing was measured. When the use as an impact-absorbing member is taken into consideration, energy-absorbing ability is 2 1.0x10 to 4 J/mm at 80% reduction of area. It is yield strength 0.1Ns/mm above 2 It is required to be the following. Each striking-energy absorption member which combined each foaming aluminum under the conditions specified by this invention about relative bulk density shows energy-absorbing ability high enough, and yield strength is low so that clearly from the table 2 showing the measurement result of the charge of a class cladding metal. On the other hand, in that for which relative bulk density used the foaming aluminum of the small test number 6 as a simple substance, although the reaction force at the time of a collision had become [yield strength] small low, energy-absorbing ability had a small fault. Moreover, yield strength was high and the reaction force at the time of a collision was large what used the foaming aluminum of the test numbers 7-10 which set up relative bulk density greatly as a simple substance in order to enlarge energy-absorbing ability. in addition, by what used polyurethane foam, even if compared with which foaming aluminum, it was markedly alike and impact absorbing power showed the low value.
[0029]
[Table 2]

表2：各種干渉部材のエネルギー吸収量と降伏強度

区分	試験番号		エネルギー吸収量 (J／mm^3)	降伏強度 (N／mm^2)
本発明例	1	0.05g/cc(50mm)、0.15g/cc(50mm) の重合せ	1．5×10^{-4} / 3．0×10^{-4}	0．04
	2	0.05g/cc(50mm)、0.25g/cc(50mm) の重合せ	2．5×10^{-4} / 8．0×10^{-4}	0．04
	3	0.05g/cc(33mm)、0.15g/cc(33mm)、0.25g/cc(33mm) の重合せ	4．0×10^{-4} / 9．0×10^{-4}	0．04
	4	0.05g/cc(10mm)、0.15g/cc(20mm)、0.25g/cc(70mm) の重合せ	7．5×10^{-4} / 1．7×10^{-3}	0．04
	5	0.05g/cc(5mm)、0.15g/cc(5mm)、0.25g/cc(5mm)、0.54g/cc(85mm) の重合せ	3．5×10^{-3} / 1．1×10^{-2}	0．04
	6	0.05g/ccの発泡アルミ	3．0×10^{-5}	0．04
	7	0.10g/ccの発泡アルミ	1．3×10^{-4}	0．3
	8	0.15g/ccの発泡アルミ	4．7×10^{-4} / 8．5×10^{-4}	0．8
	9	0.25g/ccの発泡アルミ	1．1×10^{-3} / 1．9×10^{-3}	1．9
	10	0.54g/ccの発泡アルミ	5．6×10^{-3}	6．5
	11	ブリウレタンフォーム	3．7×10^{-6}	－

エネルギー吸収量の上段は変形率５０％の場合，下段は変形率８０％の場合の値

[0030] The reduction-of-area-compressive-stress curve was investigated about the impact-absorbing member of test numbers 2-4. The reduction-of-area-compressive-stress curve is the curvilinear configuration which is not acquired in the monolayer shown in drawing 1 so that drawing 7 which shows results of an investigation may see, and the amount of energy-absorbing in 80% reduction of area is 2 1.0x10 to 4 J/mm. Yield strength is 2 0.1Ns/mm above. The following demand characteristics are satisfied. In addition, the yield point was seen for any impact-absorbing member at about 1% of reduction of area. The impact-absorbing member of the test number 5 which carried out the laminating of four kinds of foaming aluminum from which relative bulk density differs had the reduction-of-area-compressive-stress curve shown in drawing 8 . This impact-absorbing member had the fully small reaction force at the time of a collision, and 1 figure of absorbed amounts of striking energy was large. It turned out that it is used as an impact-absorbing member which presents from this the property which was very excellent.

[0031] Example 3 : (prototype of the pad for a side collision test)
As a buffing pad at the time of the collision attached in the side face of an automobile, it stuck with 0.05g [/cc] relative bulk density as shown in drawing 9 , three foaming aluminum with a thickness of 100mm and 0.10g [/cc] relative bulk density and two foaming aluminum with a thickness of 100mm, and adhesives. It is the total thickness Wp as a design value. It is 500mm. This combination was chosen from two kinds of compressive stress and the deformation curve from which the relative bulk density of 100mm thickness differs so that a reduction-of-area-compressive-stress curve might go into the slash field shown in drawing 1010 . The obtained impact-absorbing member was pressurized with the hydraulic press, and it asked for the reduction-of-area-compressive-stress curve. As shown in drawing 10 which shows a measurement result, the combination which asked for the piled-up foaming aluminum

by design computation went into the slash range field of drawing 10 as the target. From this, it was checked that the impact-absorbing member which carried out the laminating of the foaming aluminum presents the property which was excellent as a buffing pad for cars with which are satisfied of a design value.

[0032] Example 4 : (use as a bumper for automobiles)
As shown in drawing 11 , foaming aluminum 5 of 0.05g/cc of relative bulk density was cast to the facing 4 of a bumper. Since it was formed of cast, foaming aluminum 5 imitated the inside configuration of facing 4, and was fabricated. However, cutting of the foaming aluminum may be carried out and the obtained foaming aluminum may be pasted up on facing 4 so that it may correspond to the inside configuration of not only cast but the facing 4. A1100 aluminum plate 6 of 1.0mm of board thickness was pasted up on the flat field of foaming aluminum 5, and foaming aluminum 7 of 0.25g/cc of relative bulk density was pasted up on the aluminum plate 6. Since foaming aluminum 5 and 7 is pasted up through the aluminum plate 6, adhesion of cels is avoided. The reinforcement member 8 of an aluminum extruded shape was attached in the tooth back of foaming aluminum 7 by adhesion etc. The bumper to which the interior of the foaming aluminum 5 and 7 was carried out had small yield strength, and the absorbed amount of striking energy showed the big value. From this, there were few impacts given to a driver and a riding-together vehicle at the time of a collision, and presenting the property which was excellent as a bumper which protects a driver and a riding-together vehicle from a collision was checked.

[0033] Example 5 : (use as a road fence)
As shown in drawing 12 , a total of four sheets of foaming aluminum 10 and 11 of 0.54g/cc of relative bulk density, foaming aluminum 12 of 0.25g/cc of relative bulk density, and foaming aluminum 13 of 0.05g/cc of relative bulk density were pasted up on the established concrete fence 9. Since the front face tabular with the hide 14 of a cel was formed, the laminating of each used foaming aluminum 10-13 was carried out by applying adhesives to the front face directly, and sticking them on it. Thus, the obtained road fence had the small reaction force at the time of a collision, and, moreover, the absorbing power of striking energy showed the high value. In addition, although the road fence is formed by piling up various foaming aluminum 10-13 in drawing 12 , rubber, synthetic-resin form, an aluminum profile, etc. can also be used together with foaming aluminum, without being restrained by this.

[0034]
[Effect of the Invention] As explained above, by piling up the foaming aluminum from which relative bulk density differs, the impact-absorbing member of this invention has low yield strength, and, moreover, is increasing the compressive-stress integral value. Therefore, the reaction force produced at the time of a collision is pressed down, striking energy is absorbed with a big absorbed amount, and the bumper for automobiles, an impact pad, and the road fence for an impact buffer can be built. Moreover, since the reaction force at the time of a collision and the absorbing power of striking energy can be adjusted by selection of the relative bulk density of the foaming aluminum to combine, it becomes the impact-absorbing member with which are satisfied of the property required of the purpose of use.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] The reduction-of-area-compressive-stress curve about various ingredients
[Drawing 2] Relation of the reduction of area about a thing and compressive stress from which relative bulk density differs
[Drawing 3] The deformation-compressive-stress curve about that from which relative bulk density differs
[Drawing 4] The deformation-compressive-stress curve for acquiring desired value
[Drawing 5] The graph which shows that there is no anisotropy in the impact absorbing power of foaming aluminum
[Drawing 6] The impact-absorbing member which stuck two sorts of foaming aluminum from which relative bulk density differs
[Drawing 7] The reduction-of-area-compressive-stress curve of an impact-absorbing member according to a laminating condition
[Drawing 8] The reduction-of-area-compressive-stress curve of the impact-absorbing member which carried out the four-layer laminating of the foaming aluminum
[Drawing 9] The perspective view (a) and sectional view (b) showing the laminated structure of the pad for a side collision test
[Drawing 10] The reduction-of-area-compressive-stress curve of this pad
[Drawing 11] The horizontal sectional view (a) and sectional side elevation (b) of an impact-absorbing member which were included in the bumper for cars
[Drawing 12] The perspective view (a) and sectional view (b) of an impact buffer member which were applied to the road fence
[Description of Notations]
1: The 1st foaming aluminum 2: The 2nd foaming aluminum 3: Adhesives layer
F impulse force 4: Facing 5 Seven: Foaming aluminum 6: Aluminum plate 8: Reinforcement member 9: Established concrete fence 10-13: Foaming aluminum 14: Hide of a cel

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[Translation done.]

(19)日本国特許庁（ＪＰ）　(12) **公開特許公報**（Ａ）　(11)特許出願公開番号

特開平8－68436

(43)公開日　平成８年(1996)３月12日

(51)Int.Cl.⁶	識別記号	庁内整理番号	ＦＩ	技術表示箇所
Ｆ１６Ｆ　7/12				
Ｂ６０Ｒ　19/03	Ｂ			
19/22	Ａ			
Ｅ０１Ｆ　7/04				

審査請求　未請求　請求項の数７　ＦＤ　（全 ９ 頁）

(21)出願番号　特願平6－225739

(22)出願日　平成６年(1994)８月26日

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(54)【発明の名称】　発泡アルミニウム製衝撃エネルギー吸収部材及び製造方法

(57)【要約】

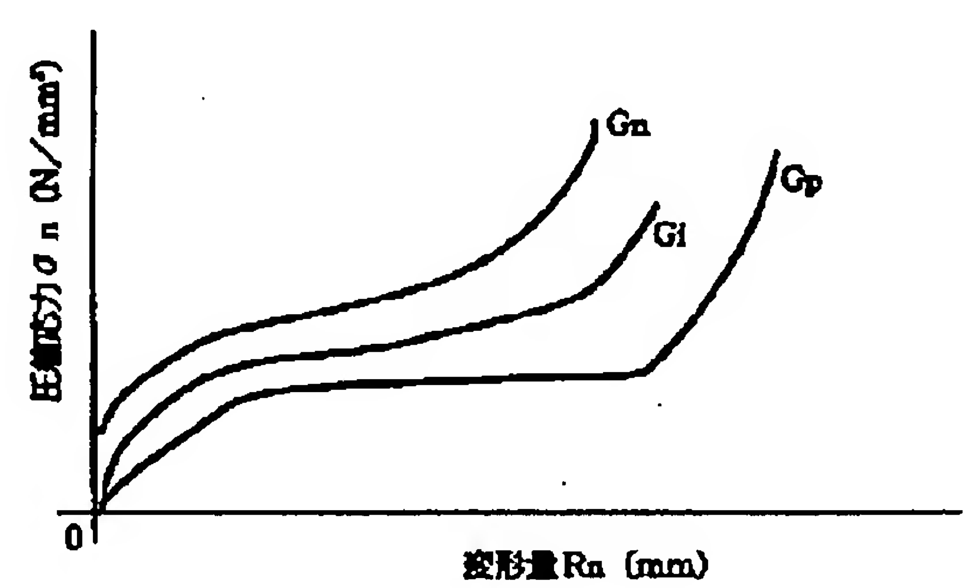
【目的】　衝突時の反力が小さく、衝撃エネルギーの吸収能が大きな衝撃吸収部材を得る。

【構成】　嵩比重G_iが０．０５～０．６ｇ／ｃｃの範囲にある発泡アルミニウム材を複数積層した構造を持ち、積層体全体の変形量R_p，圧縮応力σ_p，厚さW_p，定数a_p，b_pと単一発泡アルミニウム材の変形量R_i，圧縮応力σ_i，嵩比重G_iに応じて一義的に定まる定数a_i，b_i及び厚さW_iとの間に、近似式として

$$R_p=\sum_{i=1}^{n} R_i=\frac{b_p W_p}{100}\times \ell n\frac{\sigma_p}{a_p}=\sum_{i=1}^{n}\frac{b_i\cdot W_i}{100}\times \ell n\frac{\sigma_i}{a_i}$$

の関係が成立している。

【効果】　特性が異なる発泡アルミニウムの積層により、自動車用バンパー，衝撃吸収パッド，路側フェンス，内装材，保護容器等の用途に応じて衝撃吸収能を調整することができる。



【特許請求の範囲】

【請求項1】　嵩比重G_i が0．05～0．6g／ccの範囲にある発泡アルミニウム材を複数積層した構造を持ち、積層体全体の変形量R_p，圧縮応力σ_p，厚さW_p，定数a_p，b_p と単一発泡アルミニウム材の変形量R_i，圧縮応力σ_i，嵩比重G_i に応じて一義的に定まる定数a_i，b_i 及び厚さW_i との間に、近似式として

【数1】

$$R_p=\sum_{i=1}^{n} R_i=\frac{b_p W_p}{100}\times \ell n\frac{\sigma_p}{a_p}=\sum_{i=1}^{n}\frac{b_i\cdot W_i}{100}\times \ell n\frac{\sigma_i}{a_i}$$

の関係が成立している発泡アルミニウム製衝撃エネルギー吸収部材。

【請求項2】　請求項1記載の発泡アルミニウム製衝撃エネルギー吸収部材を使用した自動車用バンパー。

【請求項3】　請求項1記載の発泡アルミニウム製衝撃エネルギー吸収部材を使用した衝撃吸収パッド。

【請求項4】　請求項1記載の発泡アルミニウム製衝撃エネルギー吸収部材を使用した路側フェンス。

【請求項5】　請求項1記載の発泡アルミニウム製衝撃エネルギー吸収部材を使用した内装材。

【請求項6】　請求項1記載の発泡アルミニウム製衝撃エネルギー吸収部材でできた保護容器。

【請求項7】　請求項1記載の要件を満足し、且つ嵩比重が相互に異なる複数の発泡アルミニウム材を接着剤で貼り合わせる発泡アルミニウム製衝撃エネルギー吸収部材の製造方法。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、衝撃吸収パッド，保護容器，道路フェンス，自動車用バンパー，各種交通機関の内装材等として使用される衝撃吸収部材に関する。

【0002】

【従来の技術】外部から加わった衝撃エネルギーを塑性変形として吸収する衝撃吸収部材として、金属発泡体が使用されている。金属発泡体は、弾性変形を利用するゴム，バネ等と異なり、復元性のない塑性変形、すなわち発泡体自体が破壊される過程で衝撃エネルギーを吸収する。塑性変形を利用するとき、弾性復元力等によって一旦吸収されたエネルギーを相手材に与えることがないので、大きな衝撃吸収能を呈する。この種の金属発泡体として、たとえば特開昭47－8053号公報では、予め塑性変形させておくことにより初期衝撃吸収能を高めている。また、特開昭49－40214号公報では、力が加わる方向に対して直角に穿孔し、空隙率を5～60％の範囲に調節することにより、圧縮強度を低下させた衝撃吸収材が紹介されている。

【0003】

【発明が解決しようとする課題】金属発泡体は、大きな衝撃吸収能を呈するものの、依然として衝突時の反力が大きい。衝突時の反力は、特開昭49－40214号公報記載のように金属発泡体を穿孔することにより低減できる。しかし、穿孔方向と平行な衝撃に対しては穿孔による効果が小さく、エネルギー吸収能に異方性がある。また、予め塑性変形させた金属発泡体は、初期変形抵抗が小さくなるものの、全体としてのエネルギー吸収量が減少する。本発明は、このような問題を解消すべく案出されたものであり、特性が異なる金属発泡体を積層することにより、エネルギー吸収量が大きく、衝突時の反力が小さい衝撃エネルギー吸収部材を提供することを目的とする。

【0004】

【課題を解決するための手段】本発明の衝撃エネルギー吸収部材は、その目的を達成するため、嵩比重G_i が0．05～0．6g／ccの範囲にある発泡アルミニウム材を複数積層した構造を持ち、積層体全体の変形量R_p，圧縮応力σ_p，厚さW_p，定数a_p，b_p と単一発泡アルミニウム材の変形量R_i，圧縮応力σ_i，嵩比重G_i に応じて一義的に定まる定数a_i，b_i 及び厚さW_i との間に、次式の関係が成立していることを特徴とする。

【0005】

【数2】

$$R_p=\sum_{i=1}^{n} R_i=\frac{b_p W_p}{100}\times \ell n\frac{\sigma_p}{a_p}=\sum_{i=1}^{n}\frac{b_i\cdot W_i}{100}\times \ell n\frac{\sigma_i}{a_i}$$

【0006】この衝撃エネルギー吸収部材は、衝撃吸収パッド，保護容器，道路フェンス，自動車用バンパー，各種交通機関の内装材等として使用される。第1発泡アルミニウム材と第2発泡アルミニウム材とは、ろう付けや接着剤によって一体的に貼り合わされる。このとき、各発泡体の空隙部がろう材や接着剤で充填されないように、中実のアルミニウム板又は箔を介して重ね合わせることが望ましい。各種材料を圧縮変形させるとき、図1に示すように材料の性状に応じて変形率と圧縮応力との関係が異なる。なお、図1における変形率は、［（圧縮前の厚さ）－（圧縮後の厚さ）］／（圧縮前の厚さ）×100（％）で表す。衝撃吸収材料として汎用されているポリウレタンフォームでは、加えられた圧縮力に応じて弾性変形する領域が非常に小さく、僅かな圧縮力で降伏強度Aに達する。その後、ほぼ一定した圧縮応力の下で変形率が上昇するプラトー域ABになる。変形率がB

点を越えると、圧縮応力が急激に立ち上がりC点に達する。衝撃エネルギーの吸収量は、図1で示される圧縮応力の積分値に比例する。

【0007】ポリウレタンフォームは、O－Aの弾性変形が少ないことから、衝撃反力が小さい利点がある。しかし、圧縮応力の積分値、すなわち衝撃エネルギーの吸収量が少なく、優れた衝撃エネルギー吸収材とはいえない。発泡アルミニウムは、ポリウレタンフォームに比較し降伏強度が高いことから、O－Aの弾性変形量が多くなっている。弾性変形領域を越えると、一定した圧縮応力の下で変形が進行するプラトー域A－Bになる。プラトー域A－Bでは、発泡アルミニウムのセル壁が逐次圧潰されて塑性変形が進行する。大半のセル壁が圧潰されると、圧縮応力が急激に立ち上がり、C点に達する。

【0008】プラトー域A－Bの圧縮応力は、ポリウレタンフォームに比較して高いレベルにある。そのため、圧縮応力の積分値、すなわち衝撃エネルギーの吸収量は、ポリウレタンフォームに比較して非常に大きく、発泡アルミニウムが衝撃エネルギー吸収材として適していることが判る。アルミシートの表面にハニカムの六角柱状空間が直交するように、2枚のアルミシートの間にハニカムを挟んだアルミニウムハニカムは、アルミシートの面に直交する圧縮力を加えたとき、図1に材料3として示す変形率－圧縮応力曲線をとる。このときの降伏強度Aは発泡アルミニウムよりも更に高く、降伏強度Aを超えた時点で圧縮応力が一旦下がり、ハニカムが逐次崩壊するプラトー域A－Bに至る。

【0009】このようなアルミニウムハニカムは、弾性変形域O－Aが大きいことから反力が大きく初期衝撃吸収が劣る衝撃吸収部材となる。また、アルミシートの面と平行に圧縮応力が加わると、全く異なった変形率－圧縮応力曲線が示される。すなわち、アルミニウムハニカムで作成した衝撃吸収部材は、衝撃吸収能の異方性が大きく、所期の衝撃吸収能を得るために相手材に対する取付け姿勢に制約を受ける。周方向及び軸方向に関してそれぞれ複数個の切れ目を付けたアルミニウム円筒を衝撃吸収部材として使用すると、図1に材料4として示す変＊＊形率－圧縮応力曲線が得られる。このとき、加える圧縮応力は円筒の軸方向に一致させた。降伏強度Aを超えた領域にみられる複数の波は、円筒に付けた切れ目ごとにアルミ素材が圧潰されていく状態を示す。この場合も降伏強度Aが高く、初期の衝撃吸収に問題がある。また、円筒の軸方向と半径方向では変形率－圧縮応力曲線が大きく異なり、アルミニウムハニカムと同様に衝撃吸収能の異方性に起因する問題をもつ衝撃吸収部材となる。

【0010】以上のように各種材料を対比するとき、降伏強度が小さく、しかも圧縮応力の積分値が大きい発泡アルミニウムは、衝突時の反力が小さく、初期衝撃吸収に優れ、衝撃エネルギーの吸収量が大きいことが要求される衝撃吸収部材として適している。本発明は、衝撃吸収部材として優れた特性を呈する発泡アルミニウムの長所を更に活用すべく開発されたものである。同一材料でできた発泡アルミニウムは、一般的にいって空隙率に応じて降伏強度が異なる。そこで、空隙率が異なる発泡アルミニウムを重ね合わせた衝撃吸収部材では、圧縮力が加わると降伏強度の小さいものから順に圧潰される。そのため、衝突時の反発力が小さく、優れた初期衝撃吸収能が呈される。そして、プラト域A－Bでの圧縮応力は、降伏強度が大きな発泡アルミニウムに依るところが大きいことから、結果として圧縮応力の積分値、ひいては衝撃エネルギーの吸収量も大きくなる。

【0011】空隙率が異なる発泡アルミニウムは、必要に応じ適宜の枚数で積層される。積層に際し、嵩比重を空隙率の目安として各種発泡アルミニウムを重ね合わせることが実用的である。すなわち、嵩比重G_iが0．05～0．6g／ccの範囲にある発泡アルミニウム材を複数積層するとき、積層体全体の変形量R_p，圧縮応力σ_p，厚さW_p，定数a_p，b_pと単一発泡アルミニウム材の変形量R_i，圧縮応力σ_i，嵩比重G_iに応じて一義的に定まる定数a_i，b_i及び厚さW_iとの間に次式の関係が成立するように各発泡アルミニウム材の物性を選択する。

【0012】

【数3】

$$R_p=\sum_{i=1}^{n}R_i=\frac{b_p\,W_p}{100}\times\ell n\frac{\sigma_p}{a_p}=\sum_{i=1}^{n}\frac{b_i\cdot W_i}{100}\times\ell n\frac{\sigma_i}{a_i}$$

発泡アルミニウムの嵩比重は、アルミニウム溶湯に添加する発泡剤の種類，粒径，添加量，発泡条件，溶湯の冷却条件等によって調整される。発泡剤には、SiC，Al_2O_3，MgO，C等が使用される。発泡処理されるアルミニウムとしては、特別にその材質が制約されるものではないが、Al－Si系，Al－Cu系，Al－Mg系，Al－Mn系，純Al系等の全てのアルミニウム材料が使用される。

【0013】

【作用】嵩比重が異なる発泡アルミニウムを積層した衝※※撃吸収部材に圧縮力を加えると、先ず嵩比重が小さい、換言すれば降伏強度が低い第1発泡アルミニウムが塑性変形を開始する。塑性変形の開始点は、降伏強度の低下に応じ衝突の極く早い段階に設定できる。これにより、衝突時の反力を小さくし、早い段階から衝撃エネルギーを塑性変形として吸収できる。後続する段階では、降伏強度の大きな第2発泡アルミニウムが塑性変形する。そのため、図1に示したプラトー域A－Bが圧縮応力の高いレベルになり、圧縮応力の積分値、すなわち衝撃エネルギーの吸収量が大きくなる。

【0014】このとき、第1発泡アルミニウムの嵩比重と及び第2発泡アルミニウムの嵩比重との組合せを前掲した条件下で適宜選択することにより、衝突時の反力を十分に下げ、しかも衝撃エネルギー吸収量が大きなエネルギー吸収部材が得られる。また、嵩比重が相互に異なる発泡アルミニウムの積層枚数を変えることにより、使用目的に応じた特性を付与することも可能となる。以上のことから、図1に示した圧縮応力−変形率曲線を各発泡アルミニウムについて予め測定し、要求値に見合う空隙率をもつ第1発泡アルミニウム1及び第2発泡アルミニウムを選択することにより、優れた特性を呈する衝撃エネルギー吸収部材が得られる。

【0015】

【実施例】＊

＊実施例1：（変形率−圧縮応力曲線の策定）

種々の嵩比重G_n（g／cc）をもつ発泡アルミニウム材料について、変形率E_n（％）と圧縮応力σ_n（N／mm^2）との関係を実験により求めたところ、図2に示す関係があることが判った。たとえば、嵩比重が0．05g／ccの発泡アルミニウム材料では、図2に$G_{0.05}$として示す変形率−圧縮応力曲線をもっていた。この変形率−圧縮応力曲線は、式（1）で示されると見做し、定数a_n及びb_nを、個々の嵩比重をもった発泡アルミニウム材料について実験で得られたグラフの数値を次式（1）に代入することにより算出する。算出結果を表1に示す。

【0016】

【数4】

$$\left.\begin{aligned} G_{0.05} &: \ell n(\sigma_{0.05}) = \ell n(a_{0.05}) + b_{0.05} \times E_{0.05} \\ G_{0.1} &: \ell n(\sigma_{0.1}) = \ell n(a_{0.1}) + b_{0.1} \times E_{0.1} \\ G_{n} &: \ell n(\sigma_{n}) = \ell n(a_{n}) + b_{n} \times E_{n} \end{aligned}\right\} \cdots\cdots (1)$$

【0017】各種発泡アルミニウム材の組合せを設計するときは、目標とする吸収エネルギー量から具体的な寸法を定める。そこで、圧縮応力と変形量との関係が必要※

※とされる。変形率E_n（％）と変形量R_n（mm）との関係は、発泡アルミニウム材料の厚さをW_n（mm）とすると、次式（2）で表される。

$$E_n = R_n / W_n \times 100 \qquad \cdots\cdots (2)$$

設計上では具体的に変形量R_pが必要なため、圧縮応力σ_pと変形量R_pとの関係をみつけるには、図3に例示するように各々の嵩比重G_nに対応するσ_nとR_nとの関係のグラフが必要になる。式（1）及び式（2）から、次式（3）が得られる。すなわち、圧縮応力σ_nに★

★対応する変形量R_nと厚さW_nとの関係が式（3）として求められる。

【0018】

【数5】

$$\begin{aligned} \ell n(\sigma_n) &= \ell n(a_n) + b_n \times E_n \\ &= \ell n(a_n) + b_n \times \frac{R_n}{W_n} \times 100 \qquad \cdots\cdots (3) \end{aligned}$$

【0019】ここで、a_n及びb_nは、各嵩比重G_nに対応して実験式で求められている。したがって、W_nを任意に定めると、それに対応した$\sigma_n - R_n$の曲線が式（3）の計算から描くことができる（図4）。また、全体の厚さW_pは、設計上の使用条件で決定される。したがって、指定された厚さW_pよりも小となるようにW_nを任意に決定し、それぞれ単独の変形率−圧縮応力曲線を描く（図4）。図4において、W_p＝100mmで変形量−圧縮応力の関係W_p（G_p）＝W_{100}（G_{100}）☆

☆が欲しいとき、σ_nのときの$R_n = \Sigma R_i$が目標の線W_pに乗るようにW_iを何本か選定する。具体的には、図4でσ_1のとき、$R_3 = R_1 + R_2$となるようにW_{25}及びW_{75}の2本を選択する。すなわち、W_pを得るのに、W_{25}及びW_{75}の2本を重ねればよいことが判る。これを一般式でいうと、次式（4）になるようにW_i（G_i）を選択する。

【0020】

【数6】

$$R_p = \sum_{i=1}^{n} R_i \qquad \cdots\cdots (4)$$

【0021】そして、この関係を満足する曲線の組合せをみつけるのに、σ_1，σ_2・・・σ_nをトライアンドエラーで計算し、$R_n = \Sigma R_i$となるような曲線を選ぶ。本発明者等は、多数の実験から、式（4）に従って目標範囲内にある値R_pが得られることを確認した。式◆

◆（3）から変換された式（5）と式（4）から、目標値R_pを表す式（6）が求められる。式（6）が本発明の結果求められた近似的な一般式である。

【0022】

【数7】

$$R_n = \ln\left(\frac{\sigma_n}{a_n}\right)\times\frac{W_n}{100}\times b_n \quad \cdots\cdots(5)$$

$$R_p = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n}\left[\ln\left(\frac{\sigma_i}{a_i}\right)\times\frac{W_i}{100}\times b_i\right] \quad \cdots\cdots(6)$$

【００２３】式（６）における定数a_i（a_n）及びb_i（b_n）は、式（１）の図２の実測値を代入することにより、嵩比重G_i（G_n）との関連で実験データから次のように求められた。

【００２４】

【表１】

表１：定数a_n及びb_nと嵩比重G_nとの関係

嵩比重G_n g／cc	定数 a_n	定数 b_n
０．１０	０．１１	３．２
０．１５	０．６３	１．３５
０．２５	１．４２	１．３５
０．３０	１．４９	１．９３
０．５４	５．２３	２．６５

【００２５】表１のデータと式（３）の関係から、たとえばG_nが０．１のとき厚さW_nを決めると、圧縮応力σ_n及び変形量R_nのグラフが自由にW_nを変化させて多数描けることが判る。嵩比重G_nを種々変化させたグラフの中から所定のグラフを選び出して合成することにより、目標値に近似した値R_pを得ることができる。具体的には、目標値の曲線W_pの厚さW_pを設計値の総厚さ１００mm等と定め、次いでG_iに対応する定数a_i，b_iを使用して厚さW_nを１００mm以下で変化させた式（３）を各G_iに対してグラフ化し、単一部材に関する図４の曲線を多数描く。このとき、ある定数σ_nの値に関して単一部材の曲線が目標の曲線よりも必ず左側にくるように、曲線W_n（G_n）の組合せを選択する。これにより、目標値$R_p=R_1+R_2+\cdots+R_n=\Sigma R_i$が成立するよう曲線$W_i$をいくつか選択する。このとき、トータルの厚さ$W_p$により制約される範囲で、厚さ$W_n$と嵩比重$G_n$をもつ曲線の組合せは無数に存在する。そこで、製造上の容易性を考慮し、最も目標値に近く、組合せが最も簡単なものを選択して重ね合わせる。これにより、嵩比重の異なった且つ厚さの異なったものを重ね合わせ、所定の目標値W_pをもつ製品が得られる。

【００２６】実施例２：（空隙率が異なる発泡アルミニウムを重ね合わせた特性の調査）

平均粒径１０μmのＳｉＣ粒子１５重量％を含有させたアルミニウム合金ＡＣ４Ｃを、溶湯の粘性を上げ発泡反＊＊応を促進させるため７４０℃で溶解した。得られたアルミニウム溶湯に空気注入シャフトを挿入し、溶湯温度７００～６５０℃で空気注入シャフトを回転させながら圧縮空気を溶湯中に吹き込み、発泡層を形成した。この発泡層をベルト状の回転冷却体上で連続凝固させた後、切断し、幅６００mm，長さ２０００mm及び厚み１００～２００mmの発泡アルミニウムを製造した。このとき、圧縮空気の吹込み流量，空気注入シャフトの回転速度等を変更することにより、発泡アルミニウムの嵩比重を０．０５～０．５５ｇ／ｃｃの範囲に調整した。

【００２７】嵩比重０．０５ｇ／ｃｃの発泡アルミニウムを一辺８０mmの立方体に切り出し、衝撃力を加えて変形率－圧縮応力の関係を調査した。調査結果を示す図５に見られるように、Ｌ方向，ＬＴ方向，ＳＴ方向の何れに関しても、実質的に同じ変形率－圧縮応力曲線であった。このことから、発泡アルミニウムは、衝撃エネルギーの吸収能に関し異方性がないことが判る。次に、得られた発泡アルミニウムを、図６に示すように重ね合わせた。すなわち、各発泡アルミニウムを１００mm×１００mmの大きさにサイジングし、第１発泡アルミニウム１と第２発泡アルミニウム２との合計厚みが１００mmとなるように各発泡体１，２の厚みを調節した。また、発泡ウレタンを使用した接着剤層３で、第１発泡アルミニウム１と第２発泡アルミニウム２とを貼り合わせた積層体を得た（表２の試験番号１及び２）。

【００２８】接着面に直行する衝撃力Ｆを積層体に加え、エネルギー吸収量を測定した。衝撃吸収部材としての使用を考慮したとき、エネルギー吸収能が８０％変形率で1.0×10^{-4} J／mm^2以上、降伏強度を０．１N／mm^2以下であることが必要である。各組合せ材料の測定結果を示す表２から明らかなように、嵩比重に関し本発明で規定した条件下で各発泡アルミニウムを組み合わせた衝撃エネルギー吸収部材は、何れも十分に高いエネルギー吸収能を示し、降伏強度が低くなっている。これに対し、嵩比重が小さい試験番号６の発泡アルミニウムを単体として使用したものでは、降伏強度が小さく衝突時の反力が低くなっているものの、エネルギー吸収能が小さい欠点を持っていた。また、エネルギー吸収能を大きくするため嵩比重を大きく設定した試験番号７～１０の発泡アルミニウムを単体として使用したものでは、降伏強度が高く、衝突時の反力が大きかった。なお、ポリウレタンフォームを使用したものでは、何れの発泡アルミニウムに比較しても格段に衝撃吸収能が低い値を示した。

【0029】

＊ ＊【表2】

表2：各種干渉部材のエネルギー吸収量と降伏強度

区分	試験番号		エネルギー吸収量 (J/mm^3)	降伏強度 (N/mm^2)
本発明例	1	0.05g/cc(50mm) 0.15g/cc(50mm) の重合せ	1．5×10^{-4} 3．0×10^{-4}	0．04
	2	0.05g/cc(50mm) 0.25g/cc(50mm) の重合せ	2．5×10^{-4} 8．0×10^{-4}	0．04
	3	0.05g/cc(33mm) 0.15g/cc(33mm) 0.25g/cc(33mm) の重合せ	4．0×10^{-4} 9．0×10^{-4}	0．04
	4	0.05g/cc(10mm) 0.15g/cc(20mm) 0.25g/cc(70mm) の重合せ	7．5×10^{-4} 1．7×10^{-3}	0．04
	5	0.05g/cc(5mm) 0.15g/cc(5mm) 0.25g/cc(5mm) 0.54g/cc(85mm) の重合せ	3．5×10^{-3} 1．1×10^{-2}	0．04
	6	0.05g/ccの発泡アルミ	3．0×10^{-5}	0．04
	7	0.10g/ccの発泡アルミ	1．3×10^{-4}	0．3
	8	0.15g/ccの発泡アルミ	4．7×10^{-4} 8．5×10^{-4}	0．8
	9	0.25g/ccの発泡アルミ	1．1×10^{-3} 1．9×10^{-3}	1．9
	10	0.54g/ccの発泡アルミ	5．6×10^{-3}	6．5
	11	ポリウレタンフォーム	3．7×10^{-6}	−

エネルギー吸収量の上段は変形率５０％の場合，下段は変形率８０％の場合の値

【００３０】試験番号２〜４の衝撃吸収部材について、変形率−圧縮応力曲線を調査した。調査結果を示す図７に見られるように、変形率−圧縮応力曲線は、図１に示した単一層では得られない曲線形状になっており、８０％変形率でのエネルギー吸収量が１．０×１０$^{-4}$ Ｊ／ｍｍ^2 以上で降伏強度が０．１Ｎ／ｍｍ^2 以下の要求特性を満足している。なお、何れの衝撃吸収部材も、変形率１％程度で降伏点がみられた。嵩比重が異なる４種類の発泡アルミニウムを積層した試験番号５の衝撃吸収部材は、図８に示す変形率−圧縮応力曲線をもっていた。この衝撃吸収部材は、衝突時の反力が十分に小さく、衝撃エネルギーの吸収量が１ケタ大きくなっていた。このことから、非常に優れた特性を呈する衝撃吸収部材として使用されることが判った。

【００３１】実施例３：（側面衝突テスト用パッドの試作）
自動車の側面に取り付けられる衝突時の緩衝パッドとして、図９に示すような嵩比重０．０５ｇ／ｃｃ及び厚み１００ｍｍの発泡アルミニウム３枚と嵩比重０．１０ｇ／ｃｃ及び厚み１００ｍｍの発泡アルミニウム２枚と接着剤で貼り合わせた。設計値として全厚さW_P は５００ｍｍである。この組合せは、変形率−圧縮応力曲線が図１０に示した斜線領域に入るように、１００ｍｍ厚さの※嵩比重が異なる２種類の圧縮応力と変形量曲線から選択した。得られた衝撃吸収部材を油圧プレスで加圧し、変形率−圧縮応力曲線を求めた。測定結果を示す図１０に示すように、重ね合わせた発泡アルミニウムは設計計算で求めた組合せが目標どおり図１０の斜線範囲領域に入った。このことから、発泡アルミニウムを積層した衝撃吸収部材は、設計値を満足する車両用緩衝パッドとして優れた特性を呈することが確認された。

【００３２】実施例４：（自動車用バンパーとしての使用）
図１１に示すように、バンパーの表面材４に嵩比重０．０５ｇ／ｃｃの発泡アルミニウム５を鋳込んだ。発泡アルミニウム５は、鋳込みによって形成されたものであるため、表面材４の内面形状に倣って成形された。しかし、鋳込みに限らず、表面材４の内面形状に対応するように発泡アルミニウムを切削加工し、得られた発泡アルミニウムを表面材４に接着しても良い。発泡アルミニウム５の平坦な面に板厚１．０ｍｍのＡ１１００アルミ板６を接着し、アルミ板６に嵩比重０．２５ｇ／ｃｃの発泡アルミニウム７を接着した。アルミ板６を介して発泡アルミニウム５と７とを接着しているので、セル同士の接着が回避される。発泡アルミニウム７の背面に、アルミニウム押出し形材の補強部材８を接着等で取り付け

た。発泡アルミニウム５，７が内装されたバンパーは、降伏強度が小さく、衝撃エネルギーの吸収量が大きな値を示した。このことから、衝突時に運転手や同乗車に与える衝撃が少なく、衝突から運転手や同乗車を保護するバンパーとして優れた特性を呈することが確認された。

【００３３】実施例５：（道路フェンスとしての使用）図１２に示すように、既設のコンクリートフェンス９に、嵩比重０．５４ｇ／ｃｃの発泡アルミニウム１０，１１，嵩比重０．２５ｇ／ｃｃの発泡アルミニウム１２及び嵩比重０．０５ｇ／ｃｃの発泡アルミニウム１３の合計４枚を接着した。使用した各発泡アルミニウム１０～１３は、セルの皮１４で板状の表面が形成されていることから、その表面に接着剤を直接塗布して貼り合わせることにより積層した。このようにして得られた道路フェンスは、衝突時の反力が小さく、しかも衝撃エネルギーの吸収能が高い値を示した。なお、図１２では、各種発泡アルミニウム１０～１３を重ね合わせることにより道路フェンスを形成しているが、これに拘束されることなくゴム，合成樹脂フォーム，アルミ形材等を発泡アルミニウムと併用することもできる。

【００３４】

【発明の効果】以上に説明したように、本発明の衝撃吸収部材は、嵩比重が異なる発泡アルミニウムを重ね合わせることにより、降伏強度が低く、しかも圧縮応力積分値を増大させている。そのため、衝突時に生じる反力が押さえられ、大きな吸収量で衝撃エネルギーが吸収され、自動車用バンパー，衝撃パッド，衝撃緩衝用道路フェンスを構築することができる。また、組み合わせる発泡アルミニウムの嵩比重の選択によって衝突時の反力や衝撃エネルギーの吸収能を調節できるため、使用目的に

要求される特性を満足する衝撃吸収部材となる。

【図面の簡単な説明】

【図１】　各種材料についての変形率－圧縮応力曲線

【図２】　嵩比重が異なるものについての変形率と圧縮応力との関係

【図３】　嵩比重が異なるものについての変形量－圧縮応力曲線

【図４】　目標値を得るための変形量－圧縮応力曲線

【図５】　発泡アルミニウムの衝撃吸収能に異方性がないことを示すグラフ

【図６】　嵩比重が異なる２種の発泡アルミニウムを貼り合わせた衝撃吸収部材

【図７】　積層状態に応じた衝撃吸収部材の変形率－圧縮応力曲線

【図８】　発泡アルミニウムを４層積層した衝撃吸収部材の変形率－圧縮応力曲線

【図９】　側面衝突テスト用パッドの積層構造を示す斜視図（ａ）及び断面図（ｂ）

【図１０】　同パッドの変形率－圧縮応力曲線

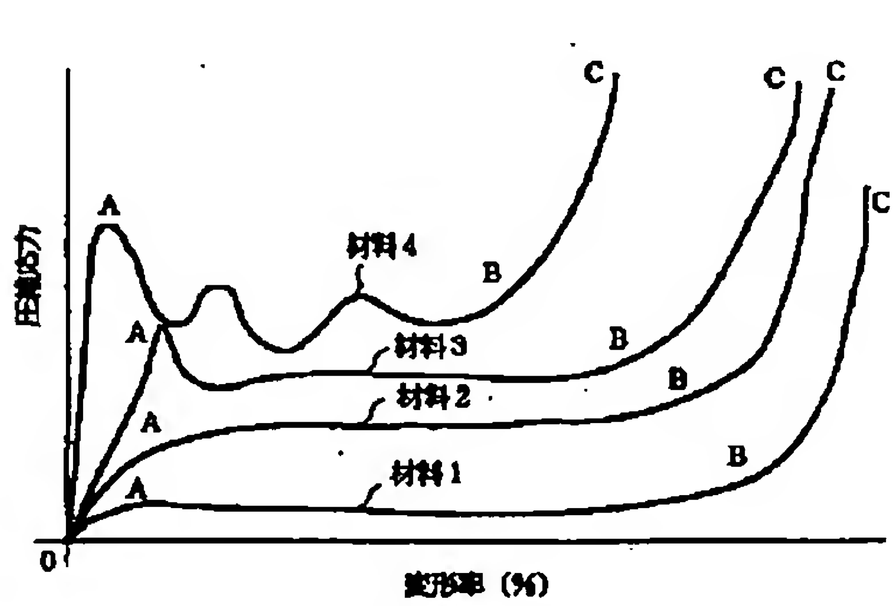
【図１１】　車両用バンパーに組み込まれた衝撃吸収部材の水平断面図（ａ）及び側断面図（ｂ）

【図１２】　道路フェンスに適用した衝撃緩衝部材の斜視図（ａ）及び断面図（ｂ）

【符号の説明】

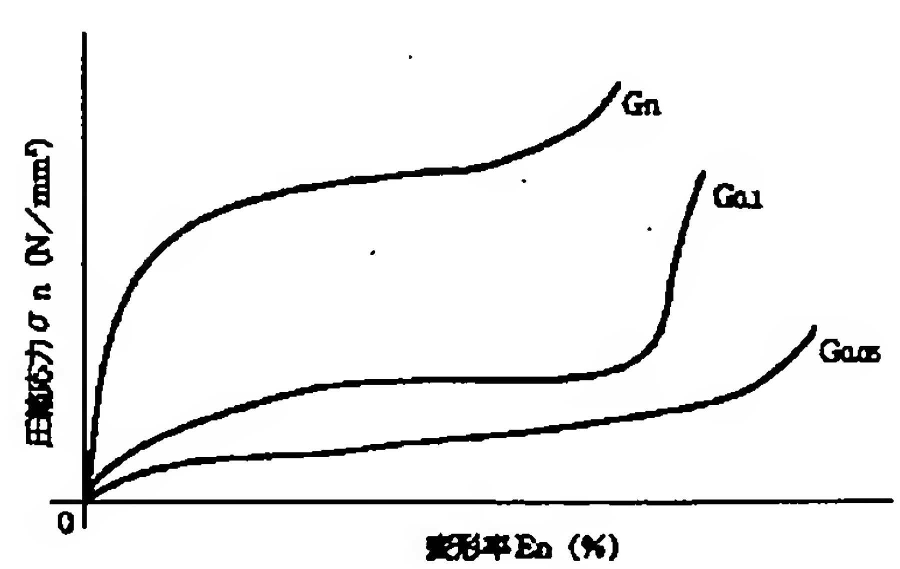
１：第１発泡アルミニウム　２：第２発泡アルミニウム　３：接着剤層　Ｆ衝撃力　４：表面材　５，７：発泡アルミニウム　６：アルミ板　８：補強部材　９：既設のコンクリートフェンス　１０～１３：発泡アルミニウム　１４：セルの皮

【図１】

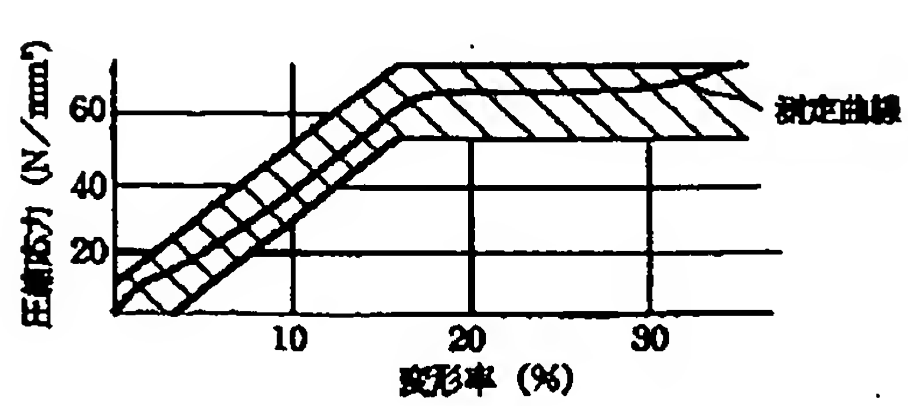


材料1：ポリウレタンフォーム
材料2：発泡アルミニウム
材料3：アルミニウムハニカム
材料4：アルミニウム形材

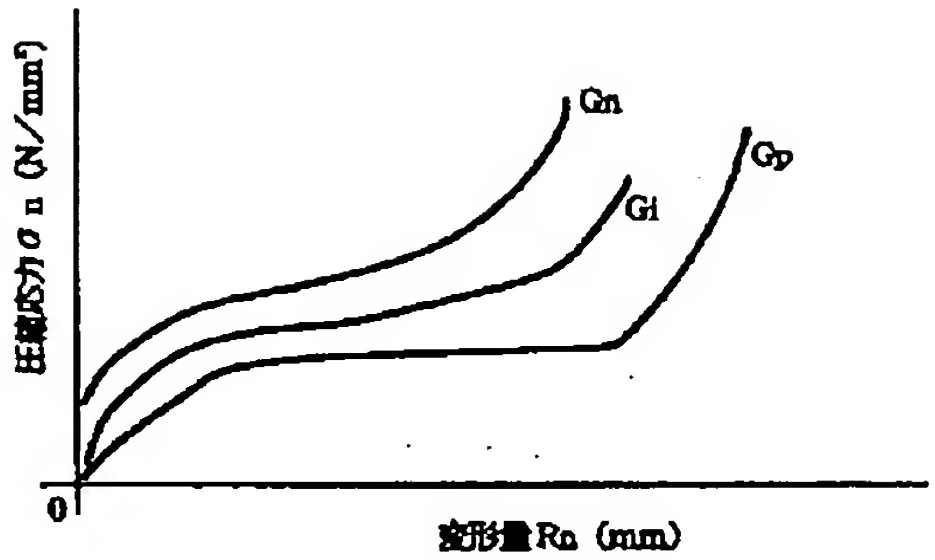
【図２】



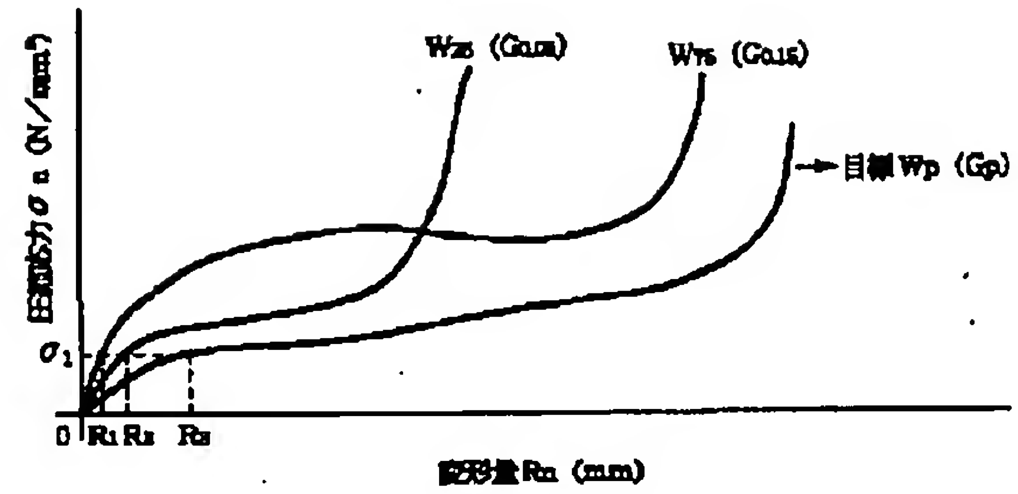
【図１０】



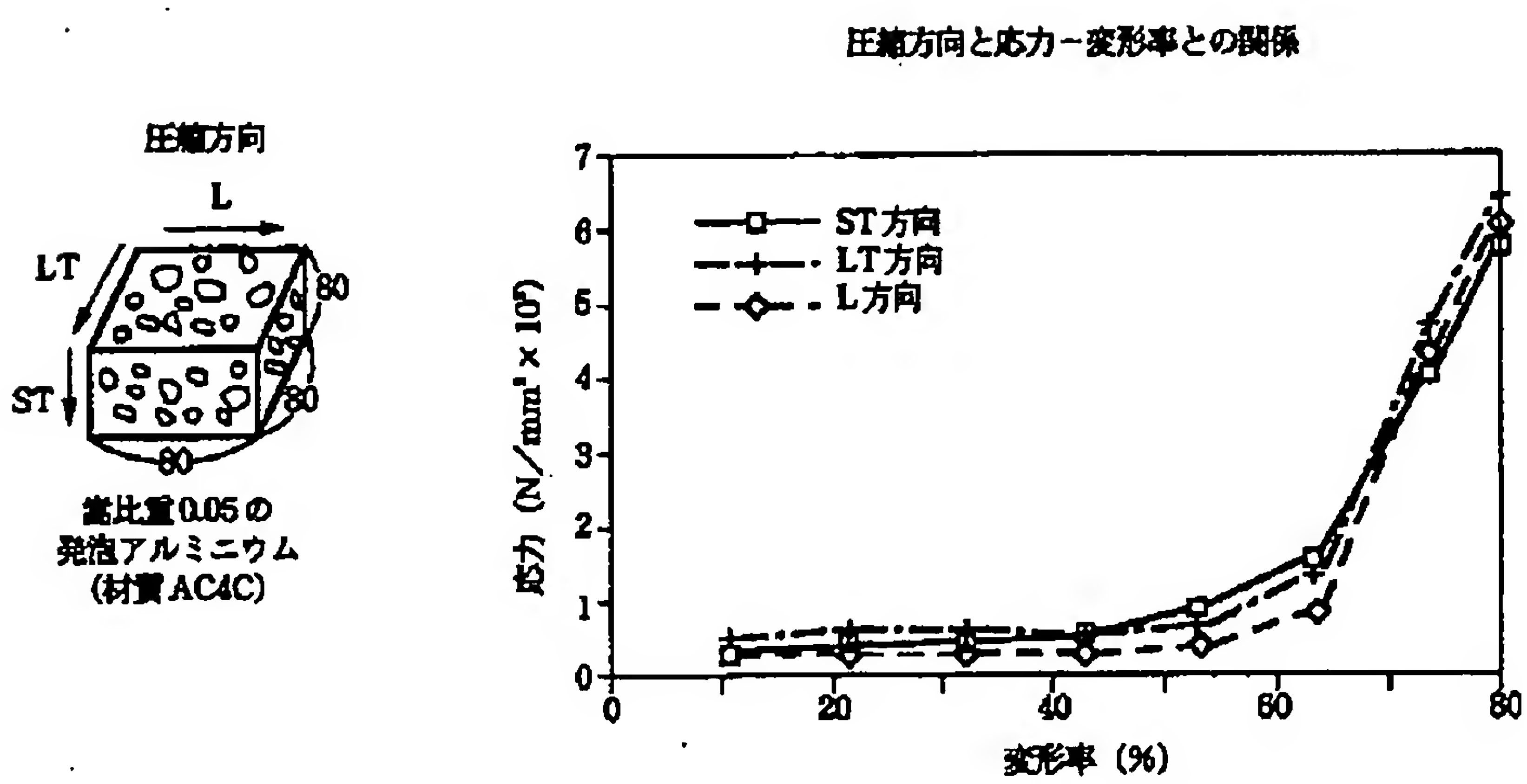
【図3】


圧縮応力σn (N/mm²)
Gn
Gi
Gp
0
変形量Rn (mm)

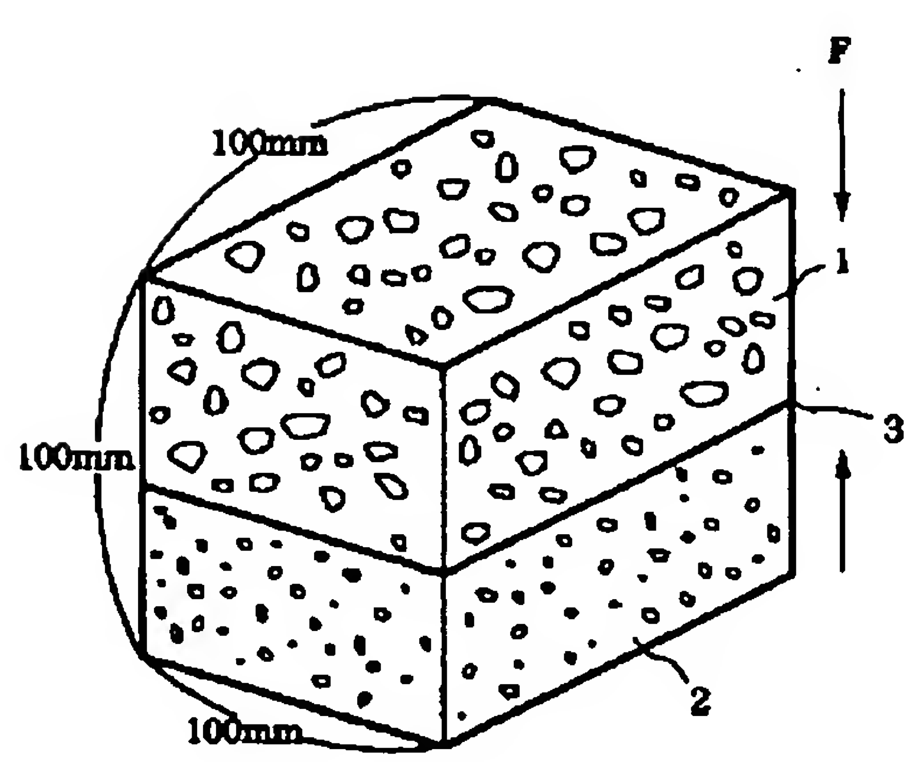
【図4】


圧縮応力σn (N/mm²)
W25 (G0.05)
W75 (G0.15)
目標Wp (Gp)
σ1
0 R1 R2 R3
変形量Rn (mm)

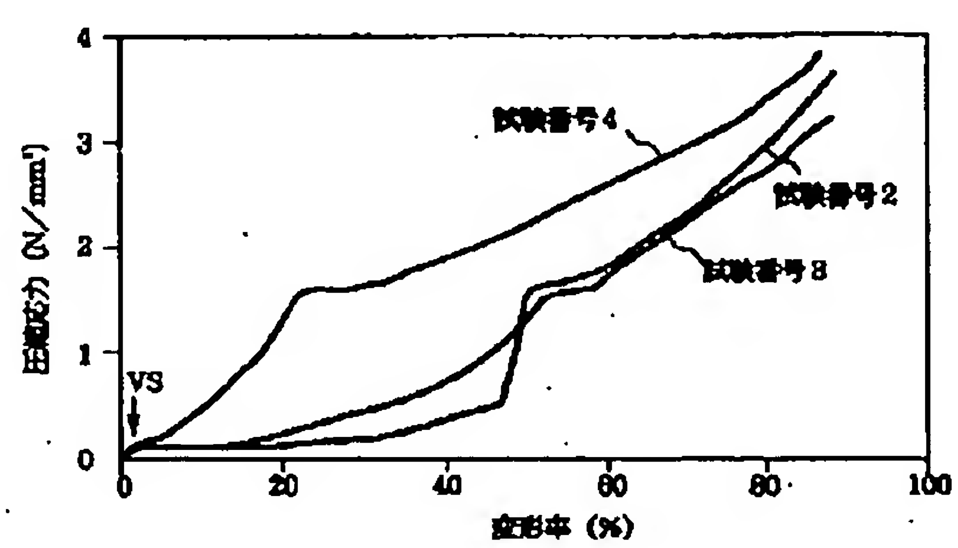
【図5】


圧縮方向と応力－変形率との関係
圧縮方向
L
LT
ST
80
80
80
嵩比重0.05の
発泡アルミニウム
(材質AC4C)
ST方向
LT方向
L方向
応力 (N/mm² × 10³)
0
1
2
3
4
5
6
7
0
20
40
60
80
変形率 (%)

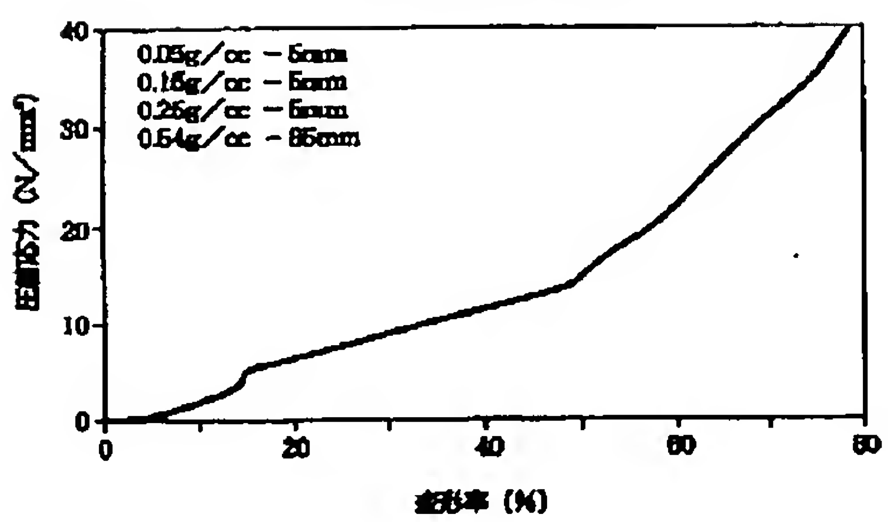
【図6】


F
100mm
100mm
100mm
1
3
2

【図7】

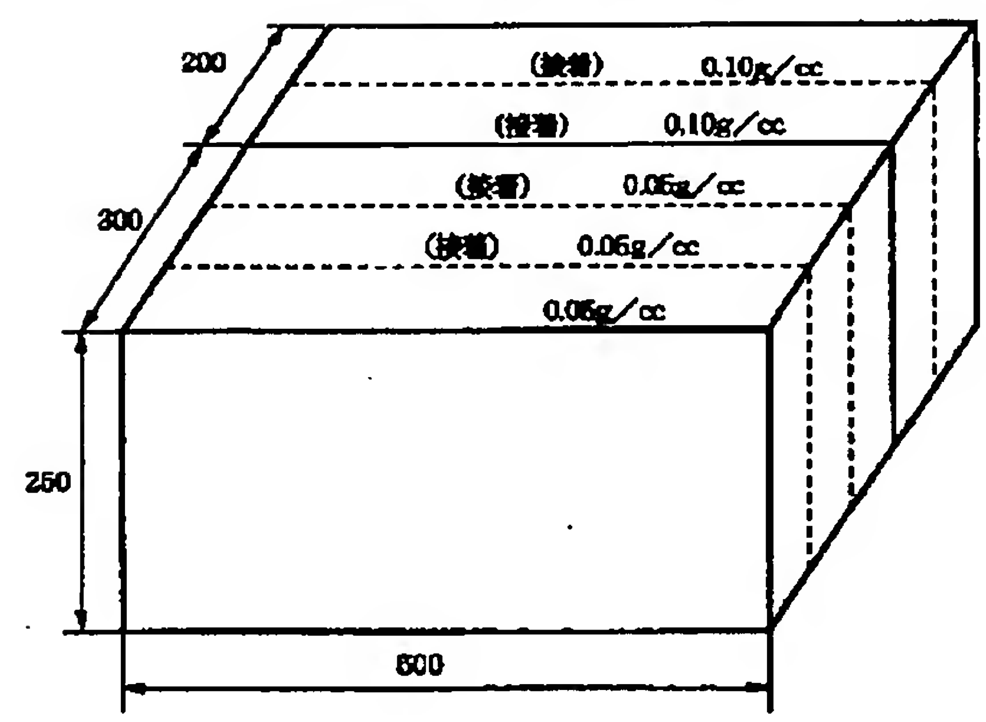

圧縮応力 (N/mm²)
試験番号4
試験番号2
試験番号3
VS
0
1
2
3
4
0
20
40
60
80
100
変形率 (%)

【図8】

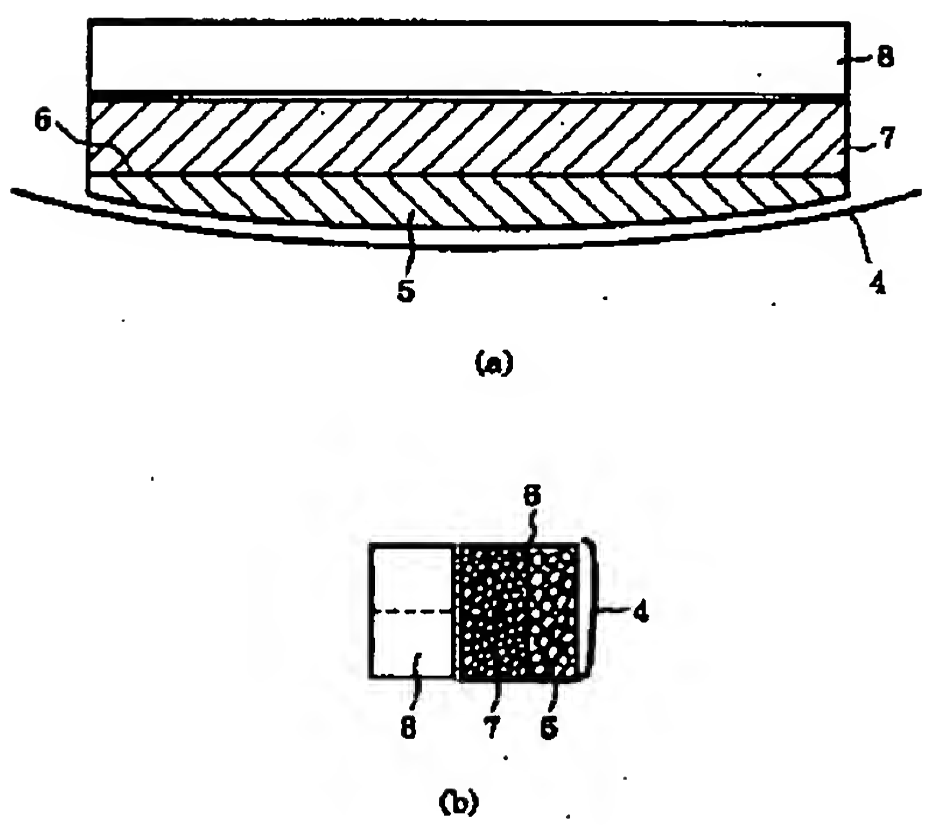


【図9】

側面衝突テスト用パッド (mm)



【図11】



【図12】